Summary

- We have developed a two photon absorption laser induced fluorescence (TALIF) diagnostic to directly measure the density of ground state neutrals in H and Kr plasma.
- In Kr plasma, the core ionization is high when \( f \approx 2.8 f_{\text{ce}} \), due to a combination of increased plasma density and neutral depletion.
- The neutral temperature is lower in high ionization plasmas, indicating neutral heating is not an active depletion mechanism.
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H Hardware

- The laser system is comprised of an Nd:YAG laser pump operated at 20 Hz, a dye laser with 101 / 83 KrI mixture for peak output at 615 nm, and a 2-stage triplet.
- Plasma is created with 100 W, 3-20 kHz rf power to initiate an ionization profile.
- The measured TALIF signal from KrI shows the slow wave (Trivelpiece-Gould wave) is damped at the lower hybrid resonance.
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Helicon Theory

- Moderate frequency \( f_e \approx f_e \) power can be coupled to the plasma in a variety of ways, depending on the mode:
  - Capacitive mode: at low density, the skin depth is larger than the system size and the wave is scattered by the plasma.
  - Inductive mode: at moderate density, the wave populates the energy of the plasma by the induction of currents.
  - Helicon mode: at high density, the helicon wave is supported. The helicon wave is a right hand polarized, electromagnetic, whistler-like wave.
- The cold plasma dispersion relation shows the slow wave (Trivelpiece-Gould wave) is damped at the lower hybrid frequency, so we expect high ionization and plasma heating when \( f_e \approx f_e \).
- The magnetic field strength is not axially uniform, so when \( f_e \approx f_e \) at the antenna (shaded region), it is possible that \( f_e \approx f_e \) of the magnetic field strength maximum.

Ionization Profiles

- The parametric scans demonstrate that ionization is highest for high power, low magnetic field, and low \( f_e \). The ionization fraction profiles for two extreme cases are shown at right.
- At \( f = 600 \text{ G} \), \( f_e = 13.0 \text{ MHz} \), the neutral density (black) is flat and the ionization fraction is low. The plasma is a uniform pink in color.
- At \( f = 1200 \text{ G} \), \( f_e = 7.0 \text{ MHz} \), the neutral density profile (black) is hollow and the electron density profile (blue) peaked. The plasma has a bright blue core.

Parametric Scans

- As the rf power is increased, the core neutral density (black triangles, left y-axis) drops and the core electron density (blue diamonds, right y-axis) increases sharply at \( P \approx 200 \text{ W} \). This is the transition from the capacitive to the inductive mode.
- As the magnetic field is increased, the plasma ionization transitions from weakly ionized to strongly ionized at \( B = 650 \text{ G} \). This is the transition from the capacitive to the inductive mode.

Neutral Depletion

- The neutral density in the core drops with increasing magnetic field, so neutral heating is not occurring.
- The neutral depletion is not observed in a static fill, constant pressure magnetic field scan. This suggests neutral pumping.
- Above a critical magnetic field strength the upstream ion saturation current is larger than the downstream, indicating the presence of an ion beam or plasma flow. Shown at right are the measured currents (black and purple) and the flow (orange) calculated from a simple Mach probe model.

Comparison to H Plasma

- As in Kr plasma, the transition from capacitive to inductive mode is observed at \( \sqrt{f_e} \approx f_e \).
- The transition to higher ionization modes is not observed in H, may be due to the additional energy required for dissociation of H2.
- \( T_e \) (black diamonds) decreases with increasing magnetic field, while \( T_e \) (red diamonds) remains constant. The large difference in the magnitude of the neutral temperature is not understood.

TALIF Basics

- Two photons from an injected laser beam excite an electronic transition in a neutral atom or ion (Figure 1).
- The absorption rate, determined by collection of spontaneous emission, is proportional to the density.
- TALIF provides greater localization than traditional LIF (Figure 2) and allows direct ground state excitation of an atomic or ion (Figure 1).
- Direct ground state excitation allows direct ground state excitation

Plasma Theory

- The parametric scans demonstrate that ionization is highest for high power, low magnetic field, and low \( f_e \). The ionization fraction profiles for two extreme cases are shown at right.
- Neutral effects results in isotopic broadening to 1.03 keV. The individual components have additive gain to the laser line width (0.18 cm⁻¹) and amplitudes.
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